BEAM-PROFILE INDICATOR FOR 184-INCH CYCLOTRON

ROBERT L. BROWN

UCRL-8767
Physics and
Mathematics

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California
Contract No. W-7405-eng-48

8854

BEAM-PROFILE INDICATOR FOR 184-INCH CYCLOTRON

Robert L. Brown

May 19, 1959

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

in

PHYSICS

United States Naval Postgraduate School
Monterey, California

Printed for the U. S. Atomic Energy Commission

Printed in USA. Price 75 cents. Available from the
Office of Technical Services
U. S. Department of Commerce
Washington 25, D. C.

BEAM-PROFILE INDICATOR FOR 184-INCH CYCLOTRON

Contents

BEAM-PROFILE INDICATOR FOR 184-INCH CYCLOTRON

Robert L. Brown

Lawrence Radiation Laboratory
University of California
Berkeley, California

May 19, 1959

ABSTRACT

A closed-circuit television chain was constructed and evaluated as a monitor for the external charged-particle beam of the 184-inch cyclotron. A sheet of plastic scintillator placed in the beam gave off light which was picked up by the camera and transmitted to the remote counting area for direct display. Magnetic shielding of the camera's deflection and focusing components was necessary for operation in the cyclotron fringing field. A lighttight enclosure for the scintillator and camera lens permitted the image orthicon to be adjusted for a light sensitivity not attainable in high ambient light levels.

A beam of 10^7 protons dispersed over an area of approximately 4 cm^2 was adequately monitored with this equipment. Beams of 10^5 particles over the same area should be discernable when the system is optimized.

BEAM-PROFILE INDICATOR FOR 184-INCH CYCLOTRON

Robert L. Brown

Lawrence Radiation Laboratory
University of California
Berkeley, California

May 19, 1959

I. INTRODUCTION

In many experimental setups the external beam of the 184-inch cyclotron is bent by a steering magnet, focused by a magnetic quadrupole, and collimated by means of a snout collimator. The resultant beam will vary in size depending on the snout collimator used and the experimental location with respect to the magnetic-quadrupole focal plane. Investigation of beam position, size, and shape is generally accomplished by exposing x-ray film, developing it, and checking for the pattern produced by charged-particle interactions with the emulsion. Each change in quadrupole settings requires a subsequent film exposure to determine its effect. Valuable accelerator time and many man hours are utilized in this tedious but necessary preliminary experimental procedure. In the interest of bettering cyclotron utilization and reducing the manpower required for this nonproductive effort, consideration of other methods of monitoring the beam were begun.

Examination of the performance potential of a closed-circuit television chain indicated that an image-orthicon camera system was probably capable of duplicating the information obtainable by means of x-ray film and that it was far superior in speed of response. Expected system resolution and sensitivity were of the same order of magnitude as that of x-ray film for short exposures. Continuous information display could be observed by both the experimenter and the cyclotron operator during the set-up procedure.

II. DESIGN CONSIDERATIONS

Three divisions of the system functions were considered in resolving the design parameters:

(a) The passage of a high-intensity, relativistic, charged-particle beam through a scintillator sheet or a phosphor screen must produce light of sufficient intensity to a picked up by the image-orthicon tube. This light pattern must duplicate the shape of the charged-particle beam and have an intensity proportional to the particle-density distribution within the beam.

(b) The camera must acquire the above light pattern, convert it into a video signal, and amplify this signal by multiplier dynodes to a usable output.

(c) Camera output must be further amplified, transmitted to the remote operating area, and adequately displayed on a monitor.

The minimum equipment required for accomplishing these system functions is diagrammed in Fig. 1. A scintillator sheet is placed in the cyclotron beam. Resulting light is reflected out of the beam by the mirror which permits the charged particles to pass directly through with little interaction. The camera lens collects this light and focuses it onto the image-orthicon photocathode. Signal output from the camera is preamplified and transmitted back to the remote operating area. There the signal is further amplified by the video amplifier and displayed on the monitor. A synchronizing-signal source maintains the proper space-time relationships between camera and video-monitor scanning.

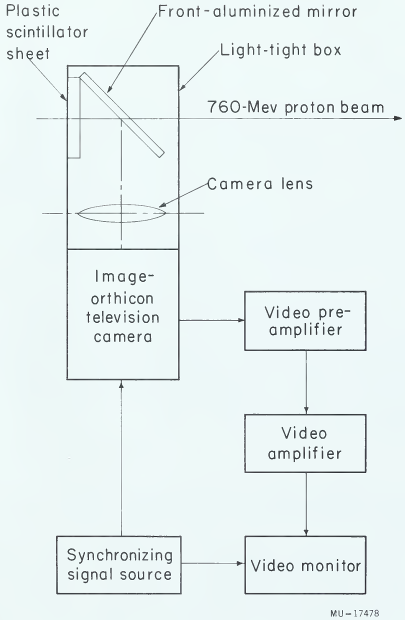


Fig. 1. Block diagram of basic camera chain.

A. Light Conversion

Many materials are capable of conerting charged particle kinetic energy into light. Inorganic scintillators such as sodium iodide and cesium iodide are particularly efficient. They were not selected for use here because of the problems associated with producing a thin screen or mosaic from them. Iodide scintillators also have undesirable aging characteristics in that they become opaque to their own scintillation-produced light. Solid plastic solutions of organic scintillation material were considered to be more desirable, for they offer acceptable light output, are available in convenient form, and can be prepared with standard shop techniques. Ordinary phosphors such as those used in cathode-ray tubes were also believed to have useful capabilities in monitoring of high-intensity charged-particle beams.

One plastic scintillator that is commonly used in counting applications was investigated to ascertain the quantity of light produced by the passage of minimum-ionizing particles such as the protons found in the cyclotron beam. The composition of this material is 97% polystyrene, 3% terphenyl, and 0.03% tetraphenyl butadiene.[1] Its specific gravity is approximately one.

According to Reynolds and Condon, less than 200/ev energy loss by a charged particle is required for the production of a scintillation photon in most plastic scintillators.[2] This figure can be likened to a quantum efficiency value in determining light output due to the passage of a minimum-ionizing particle through the material. The total energy loss per centimeter of thickness is about 2 Mev in material of density one. The number of photons produced per incident proton is

$$\frac{2 \times 10^6 \text{ ev/proton}}{2 \times 10^2 \text{ ev/photon}} = 10^4 \text{ photon/proton} .$$

For a refractive index of 1.59, the light which emerges from the plastic is approximately

$$\frac{2\pi (R \sin i)^2}{4\pi R^2} = \frac{\sin^2 i}{2} = 0.19$$

where $i = \sin^{-1} 1/1.59$.

The remainder is lost because of internal reflection.

Full cyclotron beam intensity is of the order of 10^{11} protons per sec. The number of photons emerging from the plastic scintillator per complete camera scan is

$$\frac{10^{11} \text{ protons/sec}}{30 \text{ camera scans/sec}} \times 10^4 \text{ photons/proton} \times 0.19/2 = 3 \times 10^{12}.$$

The portion of the above photons which will be incident on the image orthicon depends primarily on the solid angle subtended by the lens system. A large-aperture, short-focal-length lens is desirable. For computation purposes consider a 1-inch-aperture lens placed 1 ft from the scintillator. Geometrical considerations yield the approximate relationship

$$f = \frac{\text{area of lens}}{\text{area of hemisphere}} = \frac{\pi r^2 \text{ lens}}{2\pi R^2 \text{ hemisphere}}$$

which will suffice to predict the fraction f of the total light intercepted by a lens of radius r placed a perpendicular distance R from the scintillator screen. For r = 1/2 and R = 12 we obtain the fraction

$$f = \frac{(\pi)(1/2)^2}{2\pi(12)^2} = 0.85 \times 10^{-3}.$$

This fraction of the light will be focused onto the image-orthicon photocathode which has a usable dimension of 1.6 by 1.2 inches. Disregarding the lens' transmission losses, we find that the incident photon flux is

$$\frac{3 \times 10^{12} \text{ photons/scan}}{(1.6 \text{ in.})(1.2 \text{ in.})(6.25 \text{ cm}^2/\text{in.}^2)} \times 0.85 \times 10^{-3}$$

$$= 2.1 \times 10^{8} \text{ photons/scan/cm}^2.$$

This figure is obtained by assuming that the photons are evenly spread over the entire photocathode, a condition which exists only if the beam is evenly dispersed throughout the maximum snout-collimator cross section. The Radio Corporation of America has related the sensitivity of the type-5820 image-orthicon tube to photographic film exposed at shutter speeds of 1/30 sec with identical lens systems. Under these conditions the image-orthicon has an exposure index of ASA 500 to 1000. A typical film of this speed is Kodak Royal-X Pan film, which requires 1.6×10^8 photons per cm^2 for acceptable contrast.[4] A flux in excess of this value is available at the image-orthicon photocathode.

Based on these figures and estimations, the decision was made to use this particular plastic scintillator for conversion of charged-particle kinetic energy to light.

B. Image-Orthicon Camera Operation

Relatively complete information regarding sensitivity, resolution and operation of image-orthicon cameras under normal conditions is readily available.[5,6] Virtually no information was found regarding the operation of such equipment in magnetic fields of the order of 50 to 75 gauss and in areas where scattered high-energy particles could affect photocathode and multiplier dynode performance. The magnet shielding problem prompted the decision to construct a camera which could accomodate significant amounts of soft iron and mumetal shielding. Standard manufacturer's components and circuits were favored to reduce the engineering effort associated with building the camera. It was designed to utilize the RCA type-5820 image-orthicon tube. Most black-and-white commercial television broadcasting equipment utilizes the same type. It has good over-all sensitivity and is quite reliable. Its spectral response peaks at a wavelength of 4200 angstroms, thereby providing a good light match for the scintillator output which peaks at about 4000 angstroms.

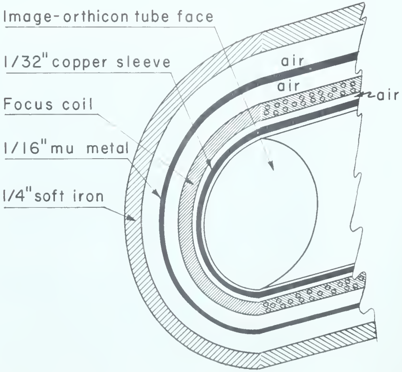
A tentative shielding system, shown in Fig. 2, was designed on the basis of experience gained from operation of photomultiplier tubes in magnetic fields. The soft iron shield shunts the external field, reducing it by a factor of at least ten. The inner shield of mumetal then reduces the remaining field to an order of magnitude comparable with that of the earth's magnetic field. The copper sleeve shields the horizontal scanning field from the electron path in the image section. No effort was expended in attempting to eliminate scattered particle effects on the tube's photocathode and multiplier dynode. Photomultiplier tubes with similar photocathodes and much higher multiplier gains are operated daily under identical conditions with no apparent ill effect.

C. Amplifier, Monitor, and Synchronizing Signal Source Operation

These units of the system presented no particular problems and no unusual techniques were involved in their design and construction. An ordinary television receiver was modified as the synchronizing signal source for the camera and as a video monitor for the experimenter. Existing amplifiers were utilized to provide the video signal input to the monitor.

The resultant system can be operated with the camera at distances of several hundred feet from the control area. Supply voltages, plugs, and cabling conform to the distribution system established at the cyclotron. This provides the user with considerable flexibility in selecting camera locations and monitoring areas.

Enclosure of the scintillator in a lighttight box attached to the end of the camera (Fig. 1) relieves the experimenter of concern regarding ambient light levels.



MU-17479

Fig. 2. Image-orthicon shielding arrangement.

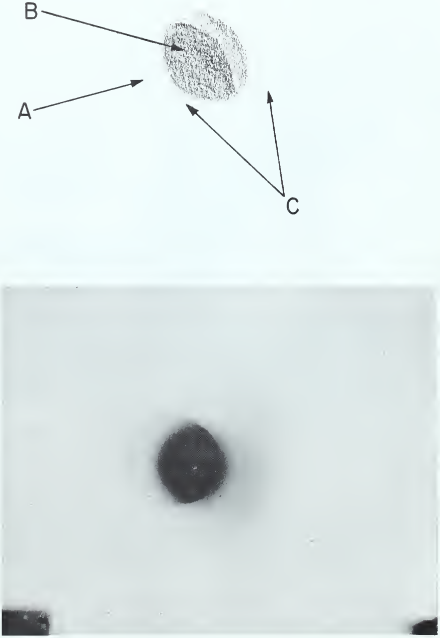
III. EQUIPMENT PERFORMANCE

The equipment was evaluated at the cyclotron with a scintillator 2.5 cm thick in the proton beam. When adjusted for normal operation, the camera was saturated by the scintillation light resulting from a beam of 10^9 protons per second spread over a 4 cm^2 area. A beam of 10^8 protons produced a reasonably well-defined and usable presentation of the beam cross section.

Two phosphor screens about 5 mils thick were also checked for light output. General Electric type Z-620 gave a usable beam profile pattern at a beam intensity of 10^{10} protons. General Electric type Z-20A failed to produce a usable pattern.

Figure 3 is a reproduction of x-ray film showing the actual beam shape and density distribution. A photograph of the monitor presentation of the beam is shown in Fig. 4. The Z-620 phosphor screen was in the beam at the time the photographs were made.

Beam-intensity readings were computed from ion-chamber current values and are only approximate in the above paragraphs. More accurate and complete investigations of equipment capabilities will be conducted in the near future.



ZN-2149

Fig. 3. Reproduction of x-ray exposure showing (a) collimator opening, (b) shape and size of the proton beam, and (c) film fogging from scattered protons.

ZN-2148

Fig. 4. Photograph of video monitor presentation of beam shown in Fig. 3.

IV. DESIRED IMPROVEMENTS

Performance of the camera chain can be optimized by modification of some components and replacement of others. These changes should include:

(a). A synchronizing signal generator should replace the receiver section of the monitor, making the system independent of external signal sources.

(b). Faster optics should be installed in place of the present achromatic lens which is of poor quality.

(c). A high-gain, low-noise video preamplifier should replace the present laboratory unit which was designed for general pulse amplifier usage.

Other changes which may eventually be made are:

1. Procurement of a high quality video monitor. The present unit has some nonlinearity in both horizontal and vertical sweeps.

2. Replacement of the RCA 5820 with the General Electric type 5294 or equivalent image-orthicon which is capable of extremely low light level operation. This alone is capable of lowering threshold beam intensity by a factor of ten.

ACKNOWLEDGMENTS

The assistance rendered by Dr. Clyde Wiegand and Mr. Dick Mack of the Lawrence Radiation Laboratory is gratefully acknowledged. They and many others contributed generously of their time and experience to ensure the timely and successful completion of this project.

The work was accomplished under the joint auspices of the United States Naval Postgraduate School and the United States Atomic Energy Commission.

REFERENCES

1. J. H. Atkinson, Jr. and B. H. Willis, High-Energy Particle Data, Volume II, UCRL-2426 (Rev), June, 1957.
2. G. T. Reynolds and P. E. Condon, Rev. Sci. Instr. 28, 1098 (1957).
3. Image-Orthicon Data Sheet 5820-10-56, Tube Division, Radio Corporation of America, Harrison, New Jersey, October, 1956.
4. Robert W. Johnston, Engineering Note, Division of Biology and Medicine, Atomic Energy Commission, Washington, 25, D. C.
5. Edward M. Noll, Closed Circuit and Industrial Television (MacMillan, New York, N. Y., 1956).
6. V. K. Zworykin and G. A. Morton, Television, Second Edition (John Wiley and Sons, New York, N. Y., 1954).